ENGR7003:

# NVH Coursework-1

**Design and development of a tuned vibration absorber to reduce flexural vibrations on a beam.**

Total Word Count: 1002

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# Introduction

Vibrations are one of the most critical aspects that need to be considered in the field of engineering design because of the impact it has on the system's performance and reliability. The study of vibration damping thus holds certain importance and requires critical thinking and in-depth knowledge. The main objective of the following coursework is to Design and develop a tuned vibration absorber to reduce flexural vibrations on a beam where one end of the primary beam is fixed and the other end is excited using an external device. To make an ideal absorber selection, both analytical and FE-based techniques are used.

## Analytical Design Calculations

Given Data: -

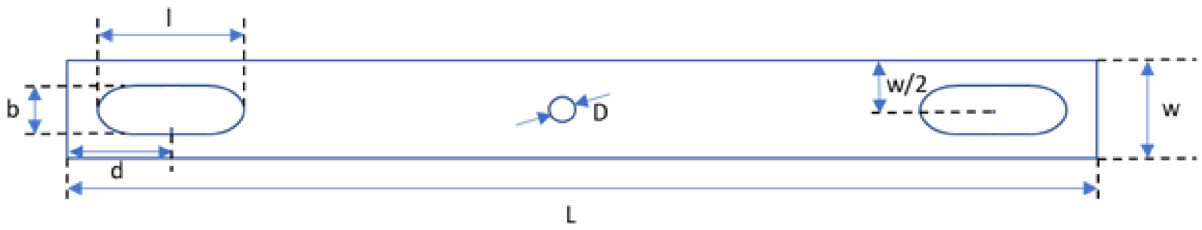


*Figure 1 Absorber dimension*

| | Absorber 1 | Absorber 2 | Absorber 3 | Units |
|---|---|---|---|---|
| **Total Length** | 0.0891 | 0.1393 | 0.1892 | m |
| **Slot length- l** | 0.0202 | 0.0202 | 0.0203 | m |
| **Slot width - b** | 0.0082 | 0.0084 | 0.0084 | m |
| **Centre of Slot - d** | 0.0147 | 0.0144 | 0.0146 | m |
| **D** | 0.0085 | 0.0065 | 0.0064 | m |
| **Width - b** | 0.0195 | 0.0205 | 0.0205 | m |
| **Thickness** | 0.0006 | 0.0006 | 0.0006 | m |
| **E (Structural Steel)** | 2.00E+11 | 2.00E+11 | 2.00E+11 | $N/m^2$ |
| | | | | |
| **Given Target Frequency** | | | **Given Force Amplitude** | |
| 68 | Hz | | 10 | N |
| 427.2566009 | rad/s | | | |

*Table 1 Absorber dimensions*

The following input variables are required for the design calculations.

$l$ - Distance of the absorber placed from the centre of the beam

b – width of the absorber beam

d – thickness of the absorber beam

E – Material properties values obtained from ANSYS Software (Ashby, 2021)

$I$ – Moment of Inertia

$K_b$- Stiffness

$\omega$ – Angular Frequency

f – frequency

Formulas used

$$\omega = \frac{\sqrt{K_b}}{Ma}$$

$$\omega = 2\pi * f$$

$$K_b = \frac{3*E*I}{l^3}$$

$$I = \frac{bd^3}{12}$$

The design approach for the analytical calculation involved multiple iterations in consideration to the assumptions made, such as the absorber beam's negligible mass. To narrow down the selection procedure using the analytical design method, three instances are taken into consideration. For the first instance, the position of the absorber was fixed and its mass was varied within the selected range (i.e. 1 to 50 gm), and this process was repeated for three fixed positions of the slot, which includes the two endpoints and the centre point. The process was carried out for each of the three offered absorber beams. This allowed an understanding of the effect in the frequency domain concerning varying mass for a particular position.

In Case 2, the position of the absorber mass on the beam was altered to calculate the required mass for achieving the given target frequency.

In the third condition, the mass of the absorber was kept constant and was iterated at different positions of the absorber to understand the model's sensitivity.

The following shows the calculated results plotted to figure out the appropriate relation between mass and frequency for varying positions in the slot for each absorber. The $\omega_a$ versus $l_a$ graph demonstrates the design's sensitivity for a fixed mass.

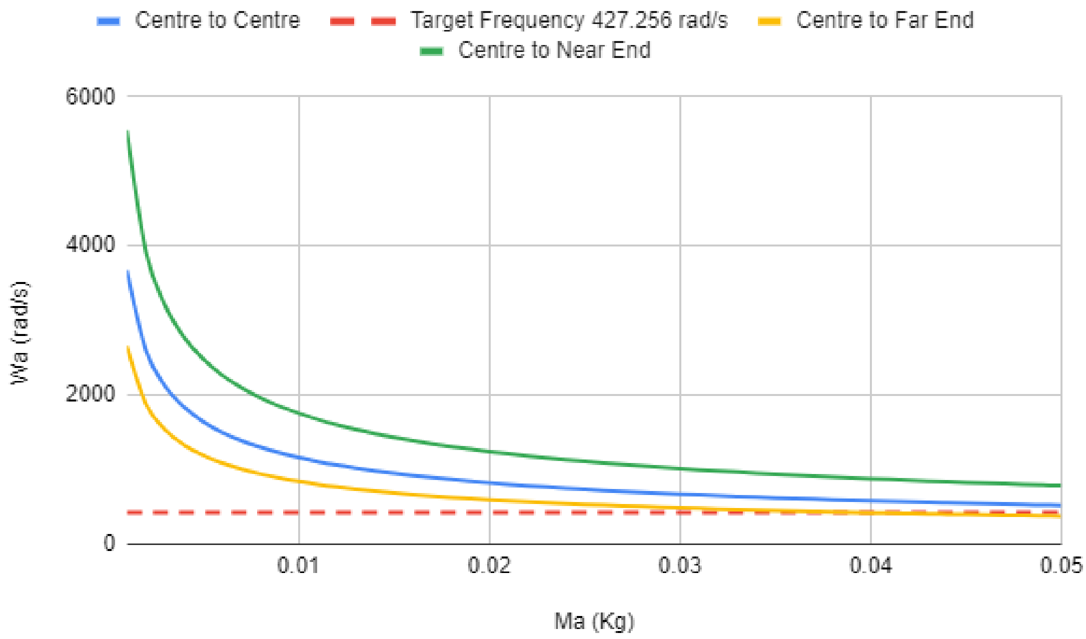


*Figure 2 Absorber 1 natural frequency with response to the varying mass*

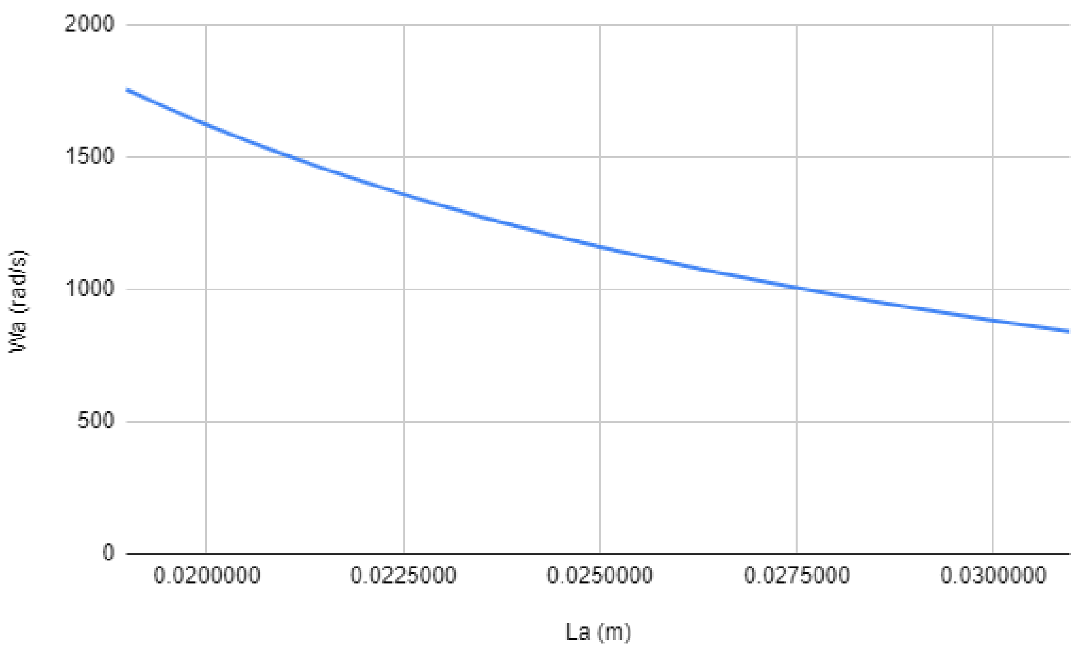


*Figure 3 Absorber 1 natural frequency with response to the varying length*

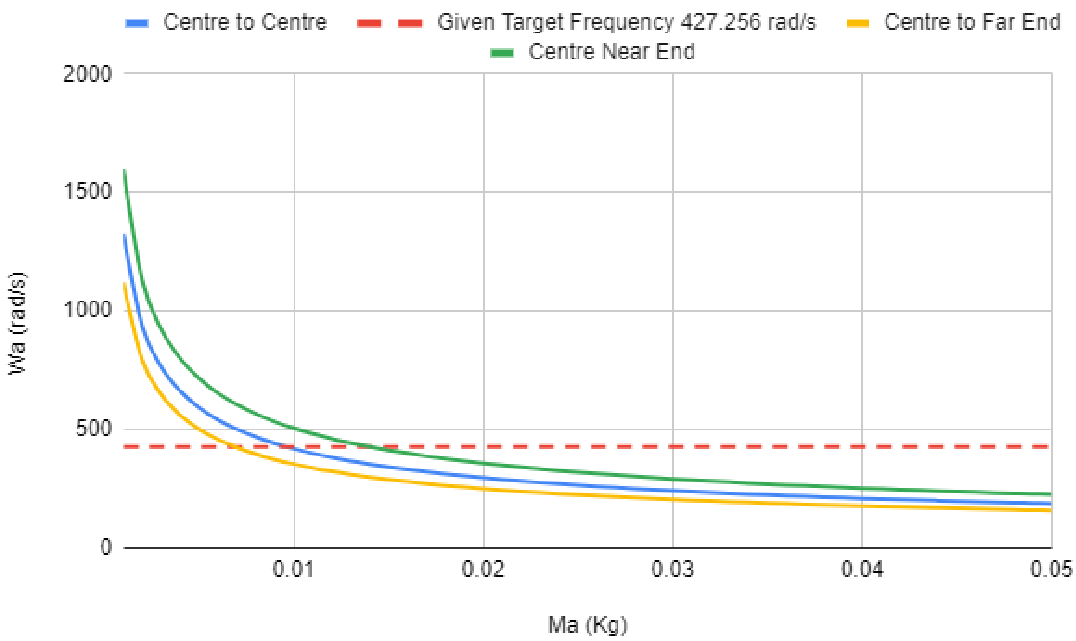


*Figure 4 Absorber 2 natural frequency with response to the varying mass*

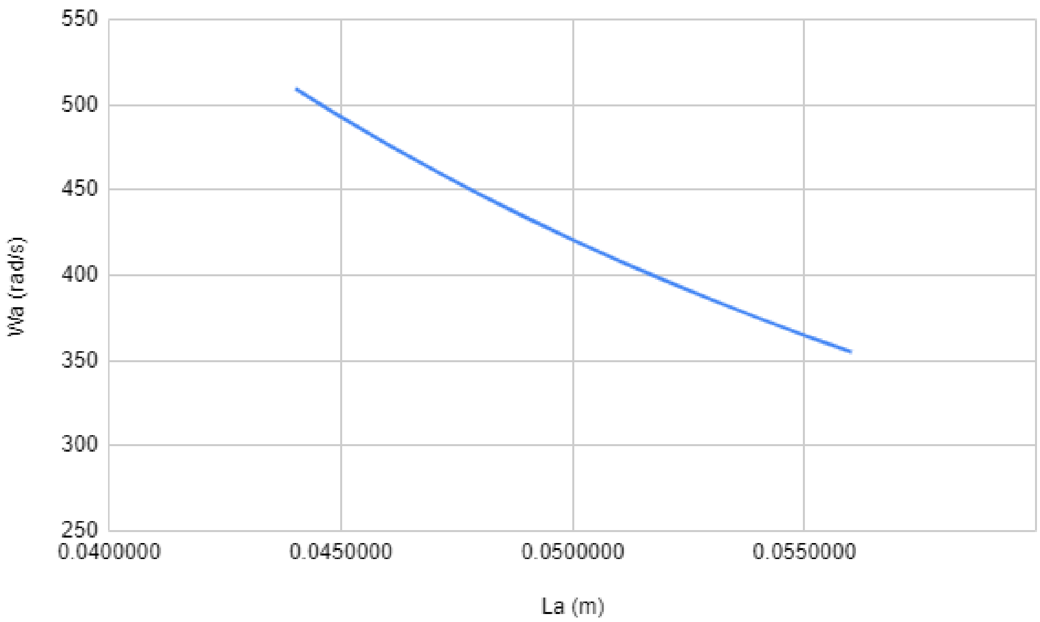


*Figure 5 Absorber 2 natural frequency with response to the varying length*

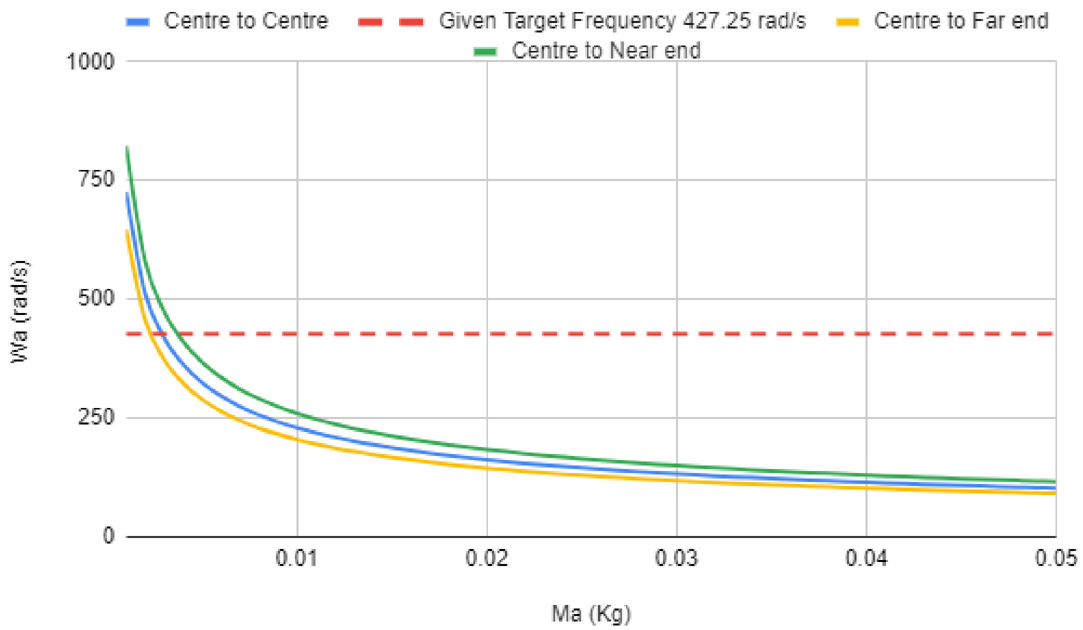


*Figure 6 Absorber 3 natural frequency with response to the varying mass*

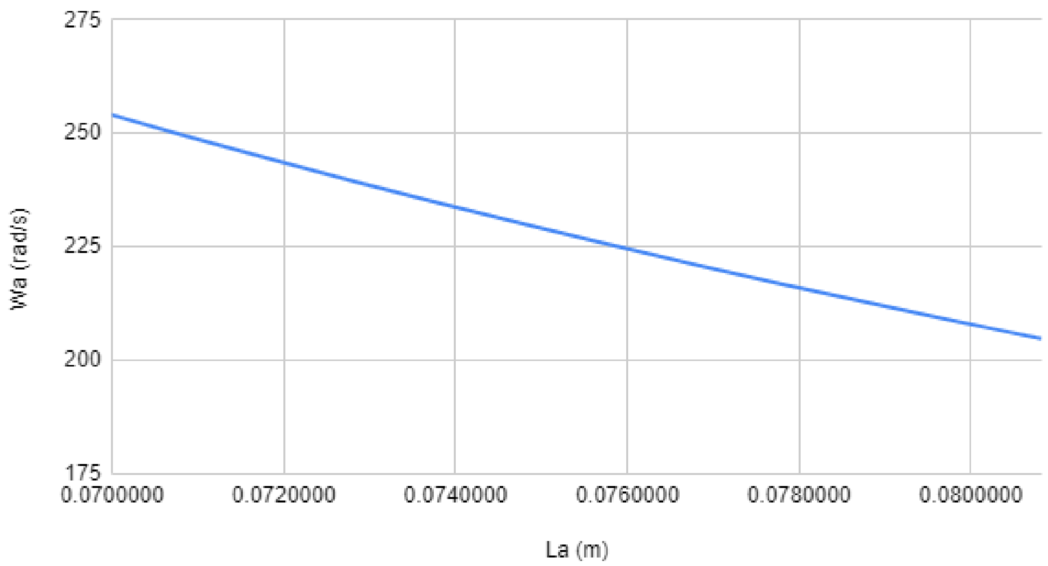


*Figure 7 Absorber 3 natural frequency with response to the varying length*

Based on the above graphs and their calculation, Absorber 2 was selected as the ideal model for the specified condition as it offered the option of using the lightest mass within the given limits making it an optimal selection. Further, the mathematical computation allowed us to determine the exact position (0.054m) for the selected mass (10gms).

Additionally, we estimated the dimension of the absorber required for designing, using the relation between density, mass, and volume in which the radius was kept constant.

$$m = \rho * \pi * r^2 * h$$

Selected dimensions based on the analytical calculation.

| Parameters | Position | Mass | Radius | Height |
|---|---|---|---|---|
| Value | 0.054m | 10gms | 0.01m | 0.0405m |

*Note: -The Position of the mass mentioned is from the centre of the absorber beam.*

*Table 2 Analytical Calculation Selected Values*

## FE method based absorber design

The Finite element method allows the analysis of a model for different materials to calculate and estimate its effects for the defined working condition. As the first step of the absorber design using the FE method, the selected absorber beam was modelled using CATIA, followed by the convergence study which was necessary to decide the optimal meshing element size to increase the accuracy level of the result considering the required computational power (Anon., 2021). For this case, we have used a meshing element size of 5.38e-004m.

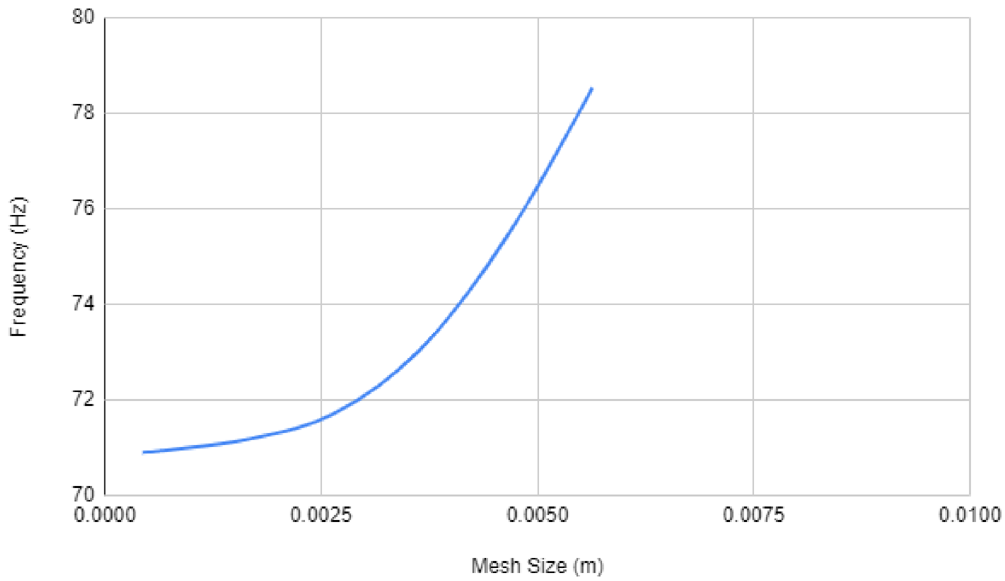


*Figure 8 Convergence Study graph*

Once the convergence study was completed, modal analysis was performed to understand the dynamic properties of the absorber in the frequency domain. An iteration of fixed length for varying mass helped to approximate the required values for absorber design using the FE method. For performing this analysis, the absorber beam was considered as a cantilever beam and was fixed from cut the section.

The obtained result from the ANSYS software was not the same as the analytical one but was within the acceptable limit since we did consider a few assumptions for analytical calculations.

| | Analytical Result | FE Result |
|---|---|---|
| Position (from the centre of the beam) | 0.054625 m | 0.054625 m |
| Frequency | 68 Hz | 68.189 Hz |
| Mass | 0.010 Kg | 0.011 Kg |

*Table 3 FE vs Analytical Comparison*

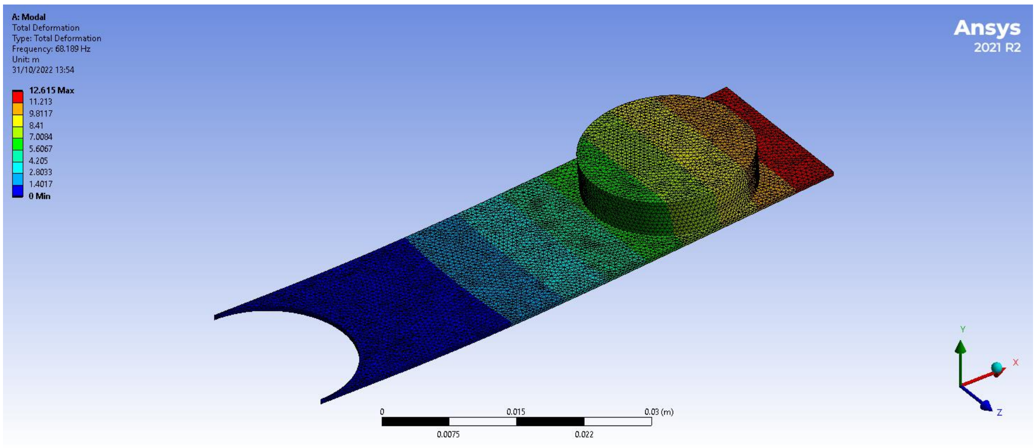


*Figure 9 Modal analysis of sectional Absorber beam*

## Comparison between FE and analytical results

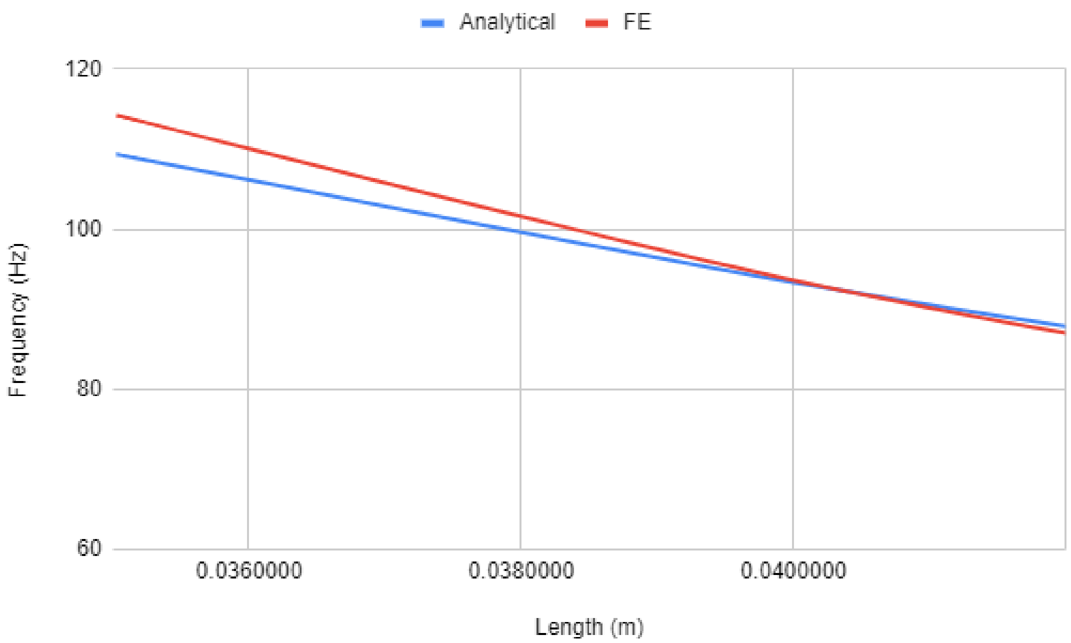


*Figure 10 FE vs Analytical (frequency with response to varying length)*

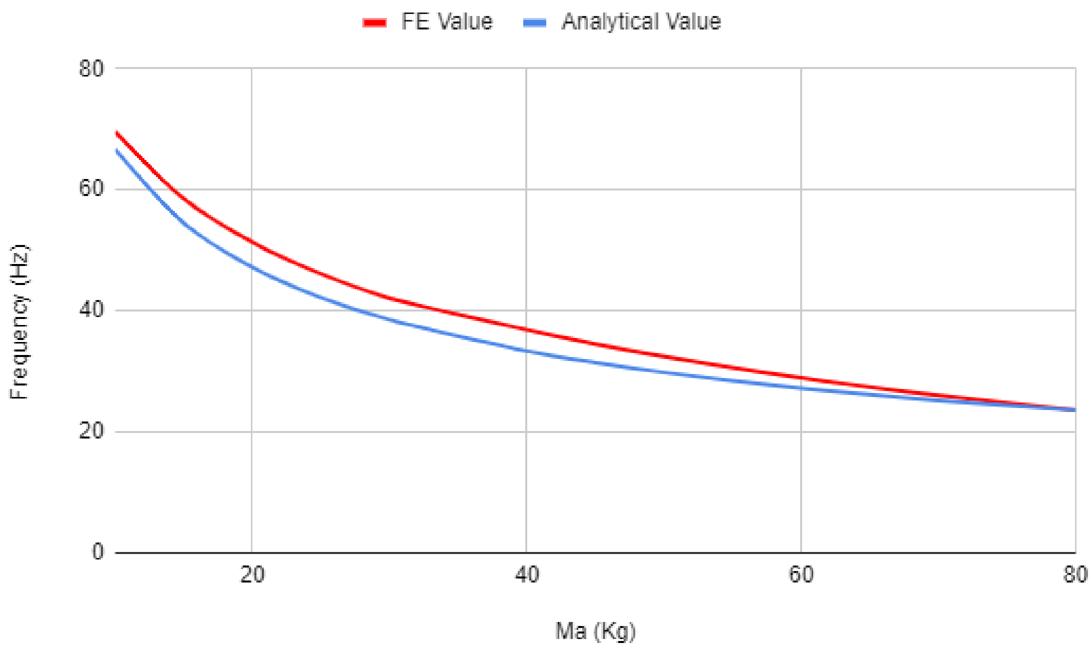


*Figure 11 FE vs Analytical (frequency with response to varying mass)*

While doing the comparison of obtained results from either method we could see a variation. The main reasons for disparities in the results are because of the assumptions considered for the analytical method and the errors involved in the FE analysis. For instance, the analytical method considers that the mass to be acting directly at a single point, whereas the FE method examines a similar to the practical scenario of it being a distributed load. Such assumptions and variations in boundary conditions lead to different results. Also, the error approximation in FE-based analysis increases with higher values.

## Absorber Validation using FE-based assembly analysis

After finalising the absorber and the subsequent parameters, the absorber model had to be validated. For this, a harmonic analysis of the primary system was performed to record its behaviour, and then the same test was repeated with the absorber mounted on the system. To perform harmonic analysis it was necessary to calculate the values for $(\alpha)$mass and $(\beta)$stiffness coefficients and specify the nodal force.

$\zeta_1 = \frac{\omega_{12}-\omega_{11}}{2\omega_1}$

$\zeta_2 = \frac{\omega_{22}-\omega_{21}}{2\omega_2}$

$\alpha = 2\omega_1\omega_2 \frac{\zeta_1\omega_2-\zeta_2\omega_1}{{\omega_2}^2-{\omega_1}^2}$

$\beta = 2\frac{\zeta_2\omega_2-\zeta_1\omega_1}{{\omega_2}^2-{\omega_1}^2}$

Calculated values are

$\zeta_1 = 0.0062 \ and \ \zeta_2 = 0.002$

$\alpha = 8.155 \ and \ \beta = \ 4.25e-007$

$\zeta_1 and \ \zeta_2 \ are \ damping \ ratios.$

The below figures show the frequency response curve for both conditions.

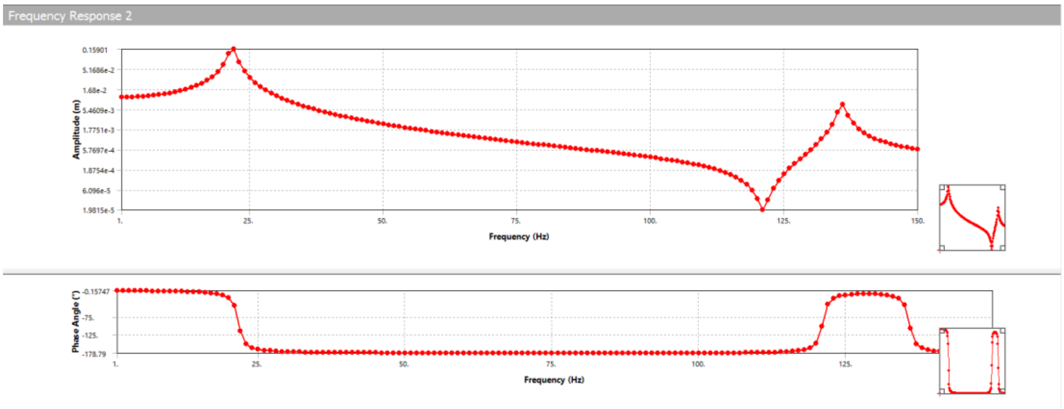


*Figure 12 Frequency Response without Absorber*

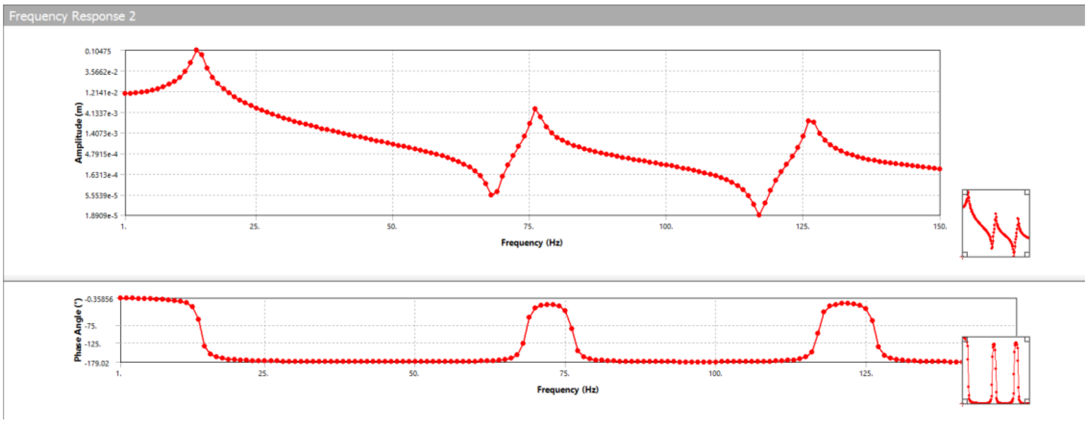


*Figure 13 Frequency Response with Absorber*

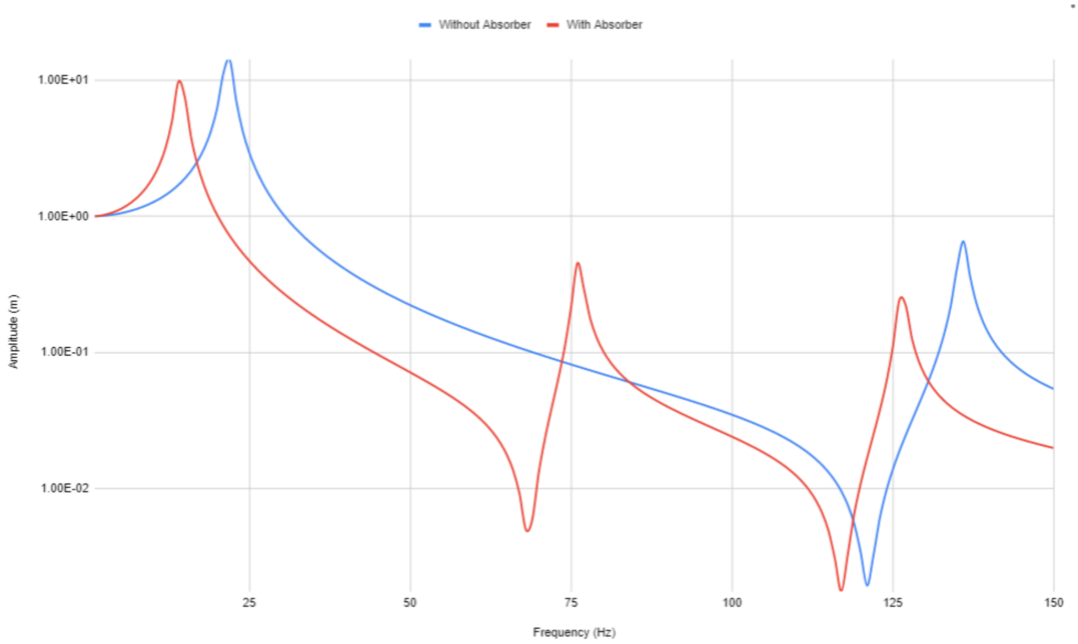


*Figure 14 Frequency Response Curve comparison*

The above graph indicates that the designed absorber is suitable for the desired working condition as we can see the reduced deflection of the beam for the given target frequency (68Hz).

For better resolution we also performed the analysis with the cluster results option enabled for an increased cluster around the peaks and troughs.

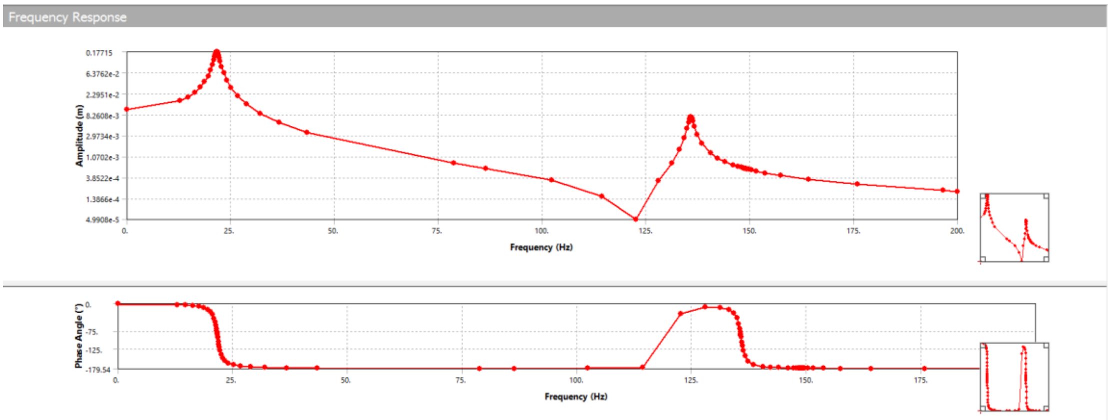


*Figure 15 Frequency Response without Absorber (With cluster on)*

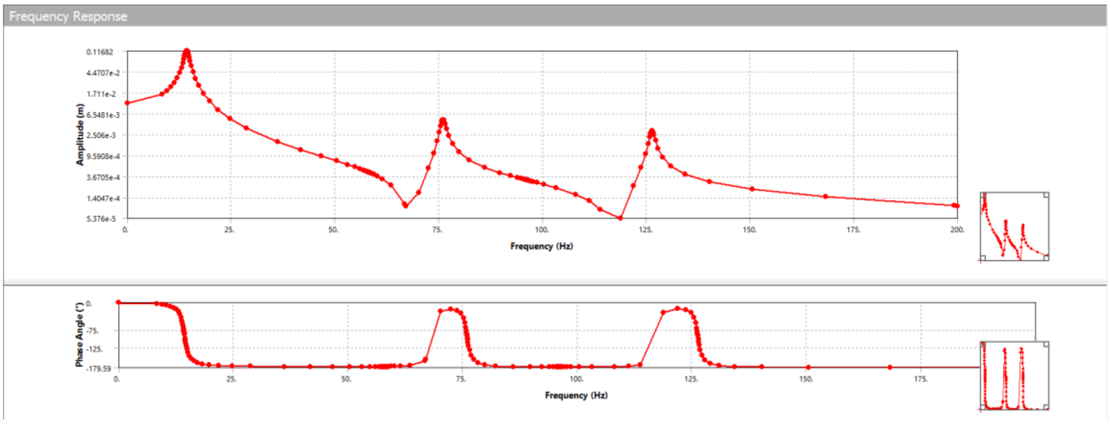


*Figure 16 Frequency Response with Absorber (With cluster on)*

## Absorber design optimisation

The absorber design optimization was carried out based on both analytical and FE results, initial decision was taken on the grounds of the results obtained from analytical calculations, which were considered for selecting the ideal absorber for the test case from the 3 available absorber options. Based on the FE results, the position and mass of the absorber were finalised. Further iterations were carried out by placing the absorber beam along the different positions on the primary system to understand the effects of changing the length to select an ideal location for the absorber on the primary system. For frequency spacing, a maximum range of 150Hz with a solution interval of 150 was decided to get better accuracy.

The following graph shows the recorded amplitude for different positions of the absorber on the primary system.

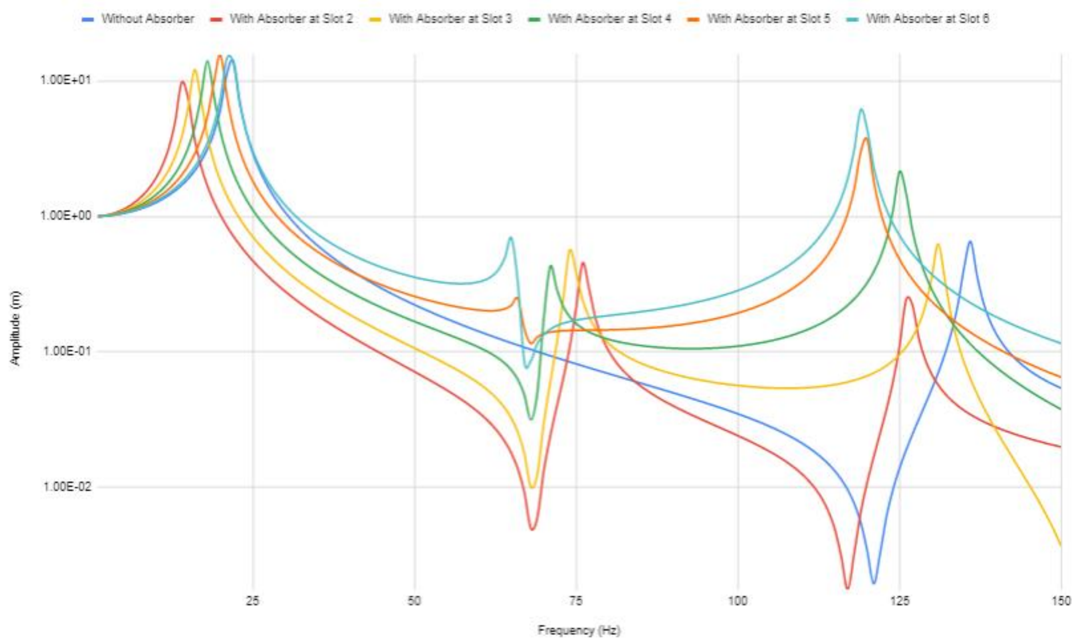


*Figure 17 Behaviour of the primary system for different positions of the absorber*

It was observed that the deflection of the main system was less when the absorber was positioned further from the fixed end. This is because, the absorber's influence decreases when it is positioned closer to the fixed end, where the system stiffness is higher. Based on this, the ideal position for the chosen absorber model was found to be 280.5mm away from the system's fixed end.

## Reflection

This coursework aided to understand the method/approach required for designing a vibration absorber for a target system, by providing an overview of the significance of the relation between mass, stiffness and frequency. Through this coursework, we also had an opportunity to compare the result obtained from analytical and finite element methods which were almost identical, suggesting the accuracy level of the virtual validation for nearly practical working conditions in which no assumptions were required.

## References


Anon., 2021. *SIMSCALE.* [Online]
Available at: https://www.simscale.com/docs/simwiki/fea-finite-element-analysis/what-is-fea-finite-element-analysis/?_gl=1*115id1p*_up*MQ..&gclid=CjwKCAjwtp2bBhAGEiwAOZZTuAo4BUs1UbOr99ecysft71pkgojdb3GS0K-SSBS47TkXYd_nZh3tKBoCCxkQAvD_BwE

Ashby, M., 2021. *ANSYS-Material property data for engineering material.* [Online]
Available at: https://www.ansys.com/content/dam/amp/2021/august/webpage-requests/education-resources-dam-upload-batch-2/material-property-data-for-eng-materials-BOKENGEN21.pdf


## Appendix

| Length (m) | Kb | Mass (Kg) | Wa (rad/s) |
|---|---|---|---|
| 0.050125 | 1757.982144 | 0.001 | 1325.88919 |
| 0.050125 | 1757.982144 | 0.002 | 937.5452374 |
| 0.050125 | 1757.982144 | 0.003 | 765.5024808 |
| 0.050125 | 1757.982144 | 0.004 | 662.944595 |
| 0.050125 | 1757.982144 | 0.005 | 592.9556719 |
| 0.050125 | 1757.982144 | 0.006 | 541.2919952 |
| 0.050125 | 1757.982144 | 0.007 | 501.139009 |
| 0.050125 | 1757.982144 | 0.008 | 468.7726187 |
| 0.050125 | 1757.982144 | 0.009 | 441.9630633 |
| 0.050125 | 1757.982144 | 0.01 | 419.2829766 |
| 0.050125 | 1757.982144 | 0.011 | 399.7706325 |
| 0.050125 | 1757.982144 | 0.012 | 382.7512404 |
| 0.050125 | 1757.982144 | 0.013 | 367.7354969 |
| 0.050125 | 1757.982144 | 0.014 | 354.3587916 |
| 0.050125 | 1757.982144 | 0.015 | 342.3431168 |
| 0.050125 | 1757.982144 | 0.016 | 331.4722975 |
| 0.050125 | 1757.982144 | 0.017 | 321.5753634 |
| 0.050125 | 1757.982144 | 0.018 | 312.5150791 |
| 0.050125 | 1757.982144 | 0.019 | 304.1798416 |
| 0.050125 | 1757.982144 | 0.02 | 296.477836 |
| 0.050125 | 1757.982144 | 0.021 | 289.3327417 |

| | | | |
|---|---|---|---|
| 0.050125 | 1757.982144 | 0.022 | 282.6805251 |
| 0.050125 | 1757.982144 | 0.023 | 276.4670076 |
| 0.050125 | 1757.982144 | 0.024 | 270.6459976 |
| 0.050125 | 1757.982144 | 0.025 | 265.177838 |

*Table 4 Absorber 2 Analytical Value*

Formula used to calculate length for different position of the absorber mass in the analytical method.

$l = (\frac{L}{2} - \frac{w}{4} - d)$ (for the centre position of the slot)

$l = (\frac{L}{2} - \frac{w}{4} - d - \frac{I}{2} + \frac{b}{2})$ (for the Near end of the slot)

$l = (\frac{L}{2} - \frac{w}{4} - d + \frac{I}{2} - \frac{b}{2})$ (for the Far end of the slot)